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MASKLESS ION BEAM LITHOGRAPHY SYSTEM

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A new type of focused ion beam column is being designed to achieve a beam spot size of less than 100nm. This column is compact and can be operated with multiple beams to enhance the throughput for lithography applications. The column has been coupled with a multicusp ion source for beam transmission and high voltage holdup testing. The 2.5-cm long column can be used to accelerate different kinds of ion beams up to 45 keV.

1. INTRODUCTION

During the past two decades, the Lawrence Berkeley National Laboratory (LBNL) has been developing multicusp ion sources for fusion, particle accelerators, ion implantation, oil well logging and proton therapy. Recently, the use of the multicusp ion source has been extended to applications such as ion projection lithography, surface modification, and micro-machining¹. Ion projection lithography (IPL) has proven to be an effective approach to print sub 0.1 μm feature sizes. The present IPL tool uses the LBNL multicusp source which produces low axial

energy spread ion beams.²

Multicusp ion sources are capable of producing large volumes of high-density, uniform and quiescent plasmas. For this reason, they are suitable for multi-beamlet formation of ions and electrons. With recent findings of very low axial ion energy spread ($<1\text{eV}$) in the coaxial source configuration³, the multicusp ion source is suitable not only for ion beam projection but also for focused ion beam lithography applications. An ion transport code IGUNE[®] has been used to simulate the ion trajectories in the accelerator column with full space charge effect.

The new FIB systems that are now being developed at LBNL can provide direct beam writing capability for surface modification, lithography and doping with high throughput. System design as well as experimental results will be presented in this paper.

2. ION SOURCE

Ion lithography presents certain advantages over its counterpart technology in terms of improved resolution and higher resist sensitivity. The ions generated in a multicusp source have a low axial energy spread, desirable in lithographic applications. The multicusp ion source, named for its characteristic B-field configuration around the



Fig. 1 Multicusp ion source

source chamber that confines the plasma efficiently. The size of the source can be as large as 30-cm diameter or as small as 2-cm diameter. A picture of a 5-cm diameter source with a planar magnetic filter is shown in Fig. 1.

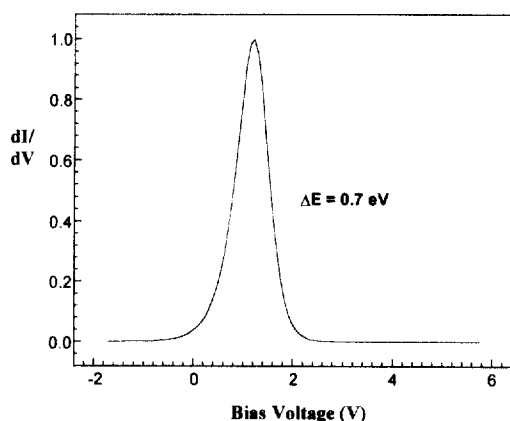


Figure 2. The axial energy spread of the ions in the multicusp ion source is as low as 0.7 eV.

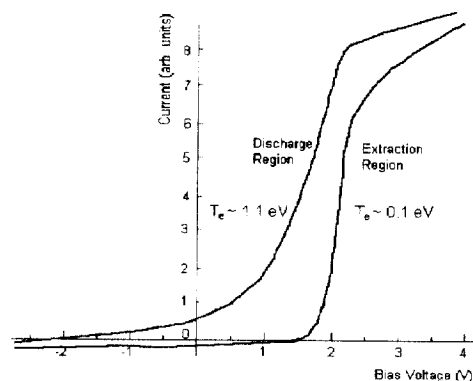


Figure 3. The energy of the electrons can be as low as 0.1 eV.

The ion axial energy spread has been found to be less than 2 eV of the multicusp source equipped with a planar filter.⁴ This ion source will be mainly used for the application described in this paper. The axial energy spread can be further reduced to 0.7 eV with a co-axial filter cage arrangement. This source arrangement can also

control the ion transverse energy by adjusting the radial plasma potential distribution. The transverse ion energy spread for the multicusp source has been measured to be about 0.2 eV⁵. Recently it has been found that this source type can also generate electrons with very low temperature. By using the filter the electron energy was lowered from 1.1 eV to 0.1 eV.

3. FOCUSED ION BEAM COLUMN

Ions can be extracted and accelerated to the desired beam energy with an all-electrostatic column. For the preliminary design of the focused ion beam (FIB) system, the beam energy of 50 keV was chosen. The ultimate goal of the FIB column is to produce a beam spot size of less than 100 nm. We are slowly but steadily improving the beam spot size to achieve this goal. The focused ion beam column will make use of split electrodes to scan the beam.

Preliminary design shows that large currents can be transported through the column to a small beam spot size. The entire column assembly consists of nine electrodes. The first part of the column is the extraction portion, the second part is the focusing section to achieve a very small beam spot size. Figure 4 shows the two parts of the FIB column. The second electrode in the first part acts as a collimator. Only a small portion of the uniform beam will be used for the application. However, even after the collimation, the beam current in the system is tens of microamps. For the specific case shown, the current at the wafer substrate would be 26 μ A for a focused beam sizes of < 1 μ m. The beam striking the second electrode is at low energy (about 1 keV). The electrode is thick enough to stand ion bombardment.

After the second electrode, the beam is transported through the column without any significant loss. The smallest aperture of the electrodes in this system is only 0.1 mm in radius. The dimensions of the electrodes for the preliminary FIB column are large enough to avoid the use of a sophisticated fabrication technique. The electrodes were mechanically drilled and glued to each other. The resulting accelerator column is shown in Fig. 5.

The total length is approximately 2.5 cm long. If the focusing portion were included it would have been approximately 4.0 cm. Beam current can be easily adjusted by varying the plasma density in the ion source or the radius of the second electrode.

multicusp ion source, 5 cm in diameter has been used. Plasma was generated using a tungsten filament. The system was able to hold up to 45 kV, and helium beam current of 5 μA was obtained at a very low plasma density.

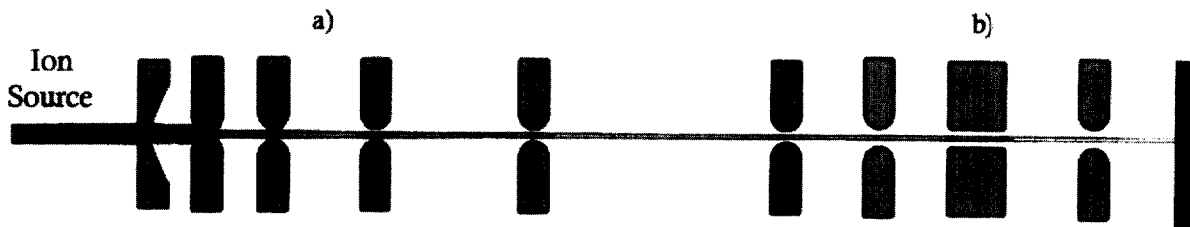


Figure 4. Focus ion beam column a) extraction portion, b) focusing portion.

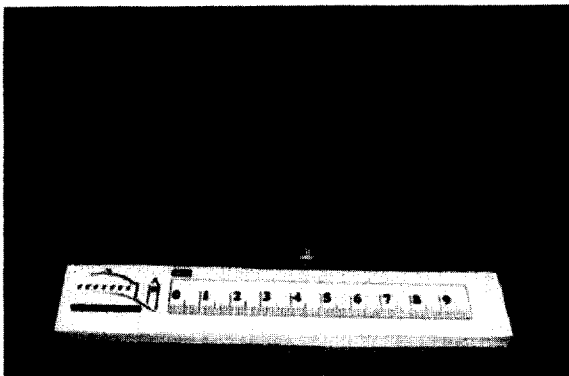


Figure 5. Photograph of the focus ion beam column.

The resulting beam spot size after focusing of this preliminary system is approximately 800 nm diameter for 100% of the beams (a σ of 300 nm). The accelerator column is being improved to achieve the sub-100 nm goal. The improved design will have a reduced number of electrodes. However, the current at the wafer substrate will be reduced to several microamps instead of tens of microamps. In the improved FIB system, micro-machining will be required to fabricate the components.

The FIB column has been tested for high voltage holdup and beam transmission. A

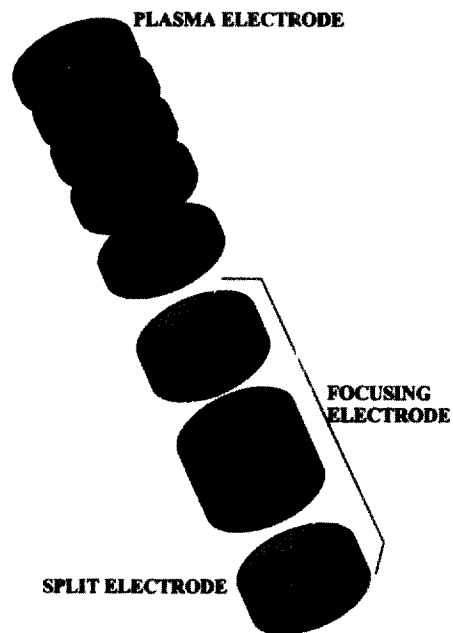


Figure 6. Focused ion beam column showing split electrodes. The above scheme can scan the beam in x and y directions.

A simplified FIB column design with the total spot size of less than 200 nm diameter will be tested in the near future. Following the computer simulation, the beam spectral brightness has been estimated to be $1.1 \times 10^5 \text{ A/cm}^2 \text{ Sr eV}$. This is a

significant improvement from the conventional plasma sources and comparable to the gaseous field ion sources (GFIS).

Beam scanning by splitting one or two of the electrodes is also being included in the new improved focused ion beam column, as shown in fig. 6. Beam spot size and beam-scanning results will be reported in the near future.

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